EPA-600/8-77-014
September 1977

URBAN STORMWATER MANAGEMENT AND TECHNOLOGY: UPDATE AND USERS' GUIDE

by

John A. Lager, William G. Smith, William G. Lynard,
Robert M. Finn and E. John Finnemore
Metcalf & Eddy, Inc.
Palo Alto, California 94303

Contract No. 68-03-2228

Project Officer

Richard Field
Storm and Combined Sewer Section
Wastewater Research Division
Municipal Environmental Research Laboratory (Cincinnati)
Edison, New Jersey 08817

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

As the base of information continues to expand through continuing research and development, it becomes increasingly important to transfer this knowledge through a concise compendium of urban stormwater practices. This report presents the most recent developments in the state-of-the-art of completed and ongoing storm and combined sewer management and abatement technologies.

Francis T. Mayo
Director
Municipal Environmental
Research Laboratory

ABSTRACT

A continuation and reexamination of the state-of-the-art of storm and combined sewer overflow technology is presented. Essential areas of progress of the stormwater research and development program are keyed to the approach methodology and user assistance tools available, stormwater characterization, and evaluation of control measures. Results of the program are visible through current and ongoing master planning efforts.

Assessment of urban runoff pollution is referenced to the developing national data base, localized through selective monitoring and analysis, and quantified as to potential source and magnitude using techniques ranging from simplified desktop procedures to complex simulation models. Stormwater pollutants are characterized by (1) source potential, (2) discharge characteristics, (3) residual products, and (4) receiving water impacts.

Control and corrective measures are separated into nonstructural, termed Best Management Practices (BMPs), and structural alternatives. Best Management Practices focus on source abatement, whereas structural alternates roughly parallel conventional wastewater treatment practices of end-of-the-pipe correction. Structural alternatives may include storage (volume sensitive) and treatment (rate sensitive) options and balances. Multipurpose and integrated (dry-wet) facilities have been the most successful with process simplicity and operational control flexibilitiy prime considerations.

Best Management Practices have decided benefits over structural alternatives--including lower cost, earlier results, and an improved and cleaner neighborhood environment--but lack quantified action-impact relationships. For combined sewer overflow abatement, increasing degrees of structural control are necessary.

Successful program implementation is illustrated for several selected case histories.

This report was submitted in fulfillment of Contract No. 68-03-2228 by Metcalf & Eddy, Inc., Western Regional Office, under the sponsorship of the U.S. Environmental Protection Agency. Work covers the period July 1975 to January 1977 and work was completed as of June 1977.

CONTENTS

CONTENTS (Continued)

CONTENTS (Concluded)

Section

FIGURES

FIGURES (Continued)

FIGURES (Concluded)

TABLES

TABLES (Continued)

TABLES (Continued)

TABLES (Continued)

TABLES (Concluded)

ACKNOWLEDGMENTS

The cooperation and assistance of key personnel from the headquarters and regional offices of the EPA, and all of the municipalities contacted and their consultants, is gratefully acknowledged by Metcalf & Eddy. Their contributions have significantly assisted in the preparation of this report.

Especially acknowledged is Richard Field, Chief of the Storm and Combined Sewer Section (Edison, New Jersey) of the USEPA Municipal Environmental Research Laboratory, Cincinnati, Ohio, and Project Officer, who provided valuable guidance and assistance during this project.

This report has been prepared in the Western Regional Office of Metcalf & Eddy, Inc., by William G. Lynard, Robert M. Finn, and E. John Finnemore under the direction of John A. Lager, Vice President, and William G. Smith, Project Manager.

The Republic of Technology is a world of obsolescence. Our characteristic printed matter is not a deathless literary work but today's newspaper that makes yesterday's newspaper worthless...

Bicentennial Essay
TIME, January 17, 1977

SECTION 1

INTRODUCTION

The quality of the surface waters of the nation reflects the aggregate effect of all discharges. As objective levels of nondegradation and restoration rise and as broad strides of countermeasure implementation are achieved, the role of the heretofore "lesser" discharges becomes increasingly important.

In response to an exploding environmental consciousness on the part of its citizens, the United States has set forth the following goals through PL 92-500, the Federal Water Pollution Control Act Amendments of 1972:

1. "To restore and maintain the chemical, physical and biological integrity of the Nation's waters." [Section 101(a)].

2. "Wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983." [Section 101(a)].

These goals cannot be achieved without recognition and assessment of all source loads and the formulation and implementation of mitigation programs drawn from an equally broad base.

URBAN STORMWATER MANAGEMENT

Urban stormwater management programs address water pollution initiated by rainfall (or frozen precipitation) impacting on developed and developing areas. Pollution is intensified as particulates are scrubbed from the air; washed from the land, pavement, and building surfaces; scoured from the collection network; and finally resuspended, transported, and deposited within the receiving waters themselves.

When stormwater runoff and municipal wastewaters are intentionally carried in the same collector system, the spills (untreated discharges) are termed combined sewer overflow. Significantly, 56% of the population in the nation's cities with 100 000 or more inhabitants [1] are served by such combined or partially combined systems. When stormwater and municipal wastewaters are collected separately, cross-connections (either direct or indirect) frequently have been found, resulting in similarly degraded overflow qualities. Finally, the separately-collected or free-discharging stormwaters alone can produce mass releases of contaminants harmful to receiving waters and in violation of objective criteria.

Assessment

Surface runoff generated problems and appropriate mitigation measures are difficult to assess because:

- The events are irregular and unpredictable
- The impacts are likely to be highly time and location variable
- Other discharges or conditions tend to mask actual results
- Relatively little usable local data are available and new data are extremely time consuming and costly to obtain
- Mitigation measures are largely conceptual and effectiveness is ill defined

These difficulties and the unquestioned need for solutions have spawned over the past decade a major research and development effort both in the United States and in other nations around the world. The result has evolved in the development and application of a new technology which emphasizes time and spatial effects and total system consciousness. Solutions are found not only in improved hardware and process operations, but even more so in the stressing of management practices that limit the spread of the problem and attack it at its source.

Because the flow quantities are high, reaching one to two orders of magnitude greater than dry-weather flows, control--whether through flow balancing, multiple uses of facilities, runoff retardation, or combinations thereof--is the focus of cost-effective planning.

Planning Process

PL 92-500 contains complex and far reaching pollution control incentives and commits the federal government to eliminate pollution of the nation's waterways. Because of their impacts on funding and program guidance, three sections of the Act have major significance: Section 303(e), the State Continuing Planning Process; Section 208, Areawide Waste Treatment Management Planning; and Section 201, Facilities Planning.

Ideally, the 303(e) plan establishes the waste loads; the 208 plan provides the regional overview and designates the 201 area and the implementing agency; and the 201 plan develops a specific project that is the most environmentally sound and cost effective for achieving the stated water quality standards.

With respect to combined sewer overflows and stormwater discharges, present construction grant policy is [2]:

> Projects involving treatment and control of combined sewer overflows and stormwater discharges may be considered only after the planning process has clearly established their cost-effectiveness. Such projects must be

considered on a case-by-case basis after a careful review of all alternative control techniques has shown that, even after industrial effluent limitations and a minimum of secondary treatment for dry-weather municipal flows are achieved, the selected alternative is needed to protect the beneficial use of the receiving waters. See PRM 75-34 (PG-61).

In spite of the rigorous restrictions, a number of major combined sewer overflow abatement projects are being funded today. Selected milestone projects are described in Section 8 of this report.

Needs

Urban stormwater management is, in itself, a continuous process. Essential to its success is a constant process of innovation, demonstration, assessment, implementation guidance, and active program feedback. Eventual program costs will be in the $10 billions [3, 4, 5]. Such a program must be founded on proven capabilities, comparable methodologies and assessment criteria, an expanding data base, and a continuous effective technology transfer.

The difficulties cannot be regarded lightly. Much has been accomplished and clear benefits derived; however, the greatest challenge--the transition from planning to realization (with noteworthy exceptions)--is still before us.

State-of-the-Art Report

In 1972, the United States Environmental Protection Agency (EPA) through its Storm and Combined Sewer Section (Edison, N.J.) authorized the preparation of a comprehensive investigation and assessment of promising, completed, and ongoing urban stormwater projects, representative of the state-of-the-art in abatement theory and technology. The report, completed by Metcalf & Eddy, Inc., in December 1973, presented in textbook format a compendium of project information on management and technology alternatives within a framework of problem identification, evaluation procedures, and program assessment and selection.

In the process, over 140 projects, totalling over $90 million, awarded under the EPA Storm and Combined Sewer Technology Research, Development and Demonstration Program were reviewed, as well as other national and local milestone programs. The report, URBAN STORMWATER MANAGEMENT AND TECHNOLOGY: An Assessment, EPA-670/2-74-040, December 1974, is available through the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22151 [Order number: NTIS-PB 240 687] and the Storm and Combined Sewer Section, EPA, Edison, N.J. 08817.

The objective of this project is to improve and accelerate the transfer of new technology in the field of urban stormwater management from the researcher to the potential user.

Presented as an UPDATE AND USERS' GUIDE, the report supplements the earlier work by directing attention to the latest developments in the field, through expansion of the data base, by the addition of example problems, and by reconstruction of key projects in a form more useful to potential decision makers. The UPDATE is designed to be used in conjunction with, and not as a replacement of, the earlier report.

Descriptions, methodologies, and problem solutions presume a general understanding on the part of the reader of urban stormwater problems and solution alternatives, such as could be gained from the earlier work or comparable firsthand experience. In this manner, it is hoped that redundancies are reduced and that new work and information are emphasized. Selected tabular information, particularly characterization data, costs, and performance criteria have been repeated where block comparisons are considered beneficial and where significant modifications have been made.

FORMAT

The report presentation is organized into five parts, each containing illustrative problem sets where applicable. A glossary of key terms is located in the appendix.

The first part, Approach Methodology, identifies the major planning guidance documents and tools available; highlights their utility in quantifying problems and setting up approaches; and demonstrates their applicability in program development.

The second part, Data Base and Normalization, provides an update of field data and approaches used to normalize these data for transferability and impact analysis.

The third part, Best Management Practices for Nonstructural Stormwater Control, summarizes recent progress in legislative, source, and nonstructural controls and attempts to assess their relative cost-effectiveness.

The fourth part, Unit Processes, provides a similar update on applied unit processes with emphasis on performance characteristics, flexibility, operational considerations, and potential cost effectiveness.

The fifth part, System Applications, emphasizes the total systems approach and illustrates through case history examples their development from concept to implementation and, if operational, to assessment.

References

The source material covered includes that which was released, published, or obtained through direct contact over the period from January 1974 through September 1976. Both United States and selected foreign literature are included. A complete bibliography is appended to the report.

Over 360 references were reviewed covering ongoing, new, and complete projects in the field of stormwater management. Considering the 33 month search span, this represents an average document generation of better than 10 per month which is indicative of the intense activity--and rapid obsolescence--of the technology and data base. Each reference reviewed was cataloged into one or more of seven broad categories and multiple subcategories as listed in Table 1. A breakdown, illustrating the distribution of source material across these categories, is shown in Figure 1.

TABLE 1. REFERENCE DISAGGREGATION AND RETRIEVAL

Category	Detailed description
1 Storage/treatment processes	• Inline storage • Offline storage • Swirl concentrators/regulators • Screening/microstraining • Sedimentation • Dissolved air flotation • Stabilization basin • Disinfection • Filtration/hyperfiltration • Biological treatment • Chemical treatment
2 Pollutant characterization	• Characterization values • Sludge/solids • Biological/microbiological • Chemical constituents • Street/land contaminants • Sediment • Nutrients • Heavy metals
3 Mathematical models	• Management • Costs • Storage and treatment • Rainfall/runoff • Collection/transport • Receiving water • Comprehensive/planning
4 Management planning	• Sediment control • Treatment control • System control • Economics • Comparison of alternatives • Source control • Sampling/data aquisition • Sewer separation • Problem characterization • Systems analysis
5. Case studies	• Pilot plants • Full-scale plant • Bench-scale tests • Full-scale systems
6. Miscellaneous articles	• Abstracts and bibliographies • Seminar papers • Cost information • O&M information • R&D projects • Legislation
7. Project memos	• Progress reports

DATA BANK

Since 1974, the University of Florida has been engaged, under EPA contract [6], in the aggregation of urban rainfall-runoff-quality data collected by others. These data are intended primarily for use in urban runoff model calibration and verification, but also may usefully serve to characterize urban runoff on a nationwide basis.

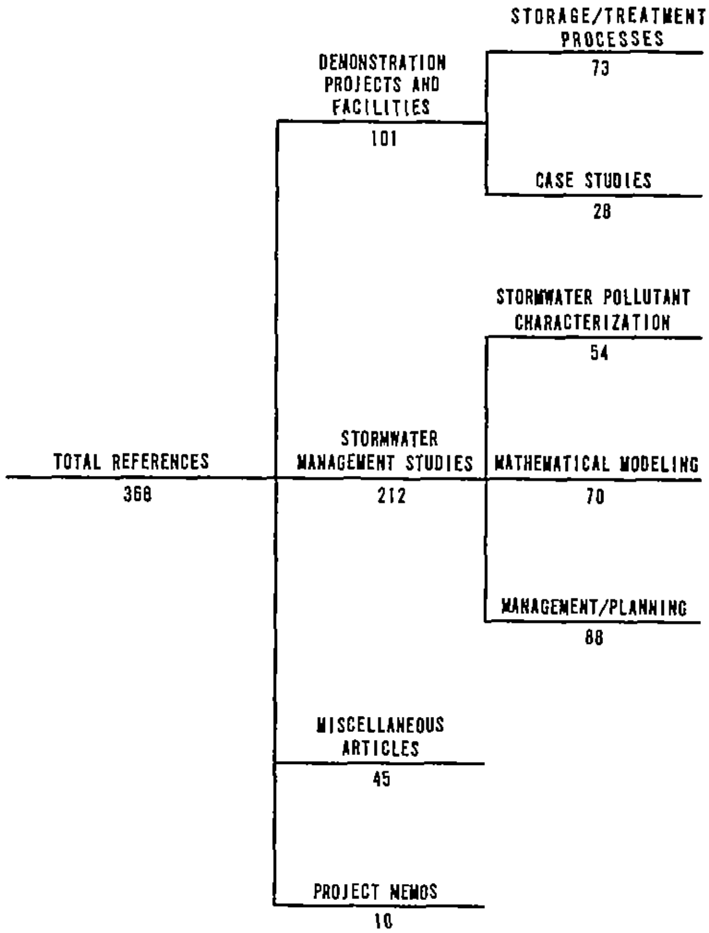

Figure 1. Source reference distribution.

Locations for which data have currently been assembled and placed on magnetic tape are listed in the Appendix. Rainfall, runoff, and quality data are available for 7 locations while 12 additional locations have only rainfall-runoff data at present. Data are provided on a storm event basis: no long-term (continuous) records are presently included. Receiving water data are also not included.

EPA encourages active use and expansion of this Data Bank. A magnetic tape containing the data will be mailed at cost to those who request it through Wayne C. Huber and James P. Heaney, Department of Environmental Engineering Sciences, University of Florida, Gainesville, Florida 32611.

In addition, it is known that there are many data sources already in existence plus potential feedback from many of the nearly 200 EPA Section 208 Areawide Waste Management Studies that may be suitable for inclusion in the Data Bank. As sources are developed periodic addenda in the form of summary reports and tape updates will be issued.

SECTION 2

CONCLUSIONS

In the 3 years since the completion and publication of the initial comprehensive assessment of urban stormwater management and technology [1], much has been published on data and methodology; many planning studies have been initiated; several demonstration projects have been completed or significantly advanced; and, most importantly, a number of major projects have reached the threshold of final design and implementation.

In terms of potential investment, a sampling of the latter projects is both staggering and reassuring.

- Chicago, Illinois - $1.8 billion program to control combined sewer overflows, partially under construction with $662 million worth of work to go under contract this year [2].

- San Francisco, California - $1.5 billion program to control combined sewer overflows and upgrade existing treatment with over $170 million in construction, advertised or awarded and projected total system operation by 1985 [3].

- Boston, Massachusetts - $0.8 billion program of regionalized treatment upgrading and combined sewer overflow control and treatment to be fully implemented by 2000 [4].

- Rochester, New York - $0.4 billion program to control combined sewer overflows, expected to go under design this year [2].

The figures are staggering because these four metropolitan areas comprise only 15% of the nation's population served by combined sewers. Reassurance comes from the fact that these cities, on the cutting edge in stormwater management, have the confidence in today's new technology to move beyond the frustrating years of study into beneficial and broad scale implementation. The impetus of design and construction works on this vast scale will greatly accelerate our base of knowledge and implementation capabilities.

Conclusions with respect to the present level of urban stormwater management technology follow in the sequences as addressed in the body of the report.

APPROACH METHODOLOGY

The basic approach concept may be viewed as a four step process: (1) quantifying the need, (2) selective field monitoring, (3) cost-effectiveness assessment, and (4) impact simulations.

- Tools for analysis range from relatively simple desktop procedures to highly complex digital computer simulations. Of the available guides, the EPA-MERL guide [5] promises the greatest utility for the user.

- Models are available in four application categories as shown in Table 2. There are considerable variations in model complexity and utility within each level.

TABLE 2. LEVELS OF STORMWATER MANAGEMENT MODELS

Analysis level	Model type	Model complexity	Purpose of model	Model characteristics
I	Desktop	Low to medium	Problem assessment, preliminary planning, alternative screening	No computers. Equations, nomographs based on statistical analyses of many years of records.
II	Continuous simulation	Low to medium	Problem assessment, planning, preliminary sizing of facilities (particularly storage), alternative screening. Assess long-term impacts of designs.	Program of few hundred to few thousand statements. Uses many years of rainfall records with daily time steps, or worst 2 years with hourly time steps. May include flow routing and continuous receiving water analysis.
III	Single event simulation	Medium to high	Analysis for design, detailed planning	Program to over 10 000 statements. Higher modeling precision, from rainfall through sewers, possibly to receiving waters. Short-time steps and simulation times. Fewer alternatives to be evaluated.
IV	Operational	Medium	Real-time coverage of sewerage systems	Uses telemetered rainfall data and feedback from sewer system sensors to continually make short-term predictions of system responses, and so produce control decisions during storms.

Desktop procedures may be adequate where a gross assessment is required of the relative loads of various sources and their impacts on water quality. Continuous, simplified models add the benefits of total system perspective for problem identification and assessment for advanced planning, while detailed models enable final design evaluations and postconstruction assessments.

- In the final analysis, however, there is no substitute for experienced professional engineering evaluation. The "least common denomination solution" does not exist whether it be aimed towards design storm selection, impact analysis, cost assessment, or public acceptability evaluation.

STORMWATER CHARACTERISTICS

Characteristics of particular interest to the designer-manager are: (1) sources of pollutants, (2) discharge "end of the pipe" loadings, (3) process residuals, and (4) receiving water impacts. A logical fifth category, beneficial reuse, is an emerging research need.

- Major stormwater pollutant sources and the related data base activities are shown in Figure 2.

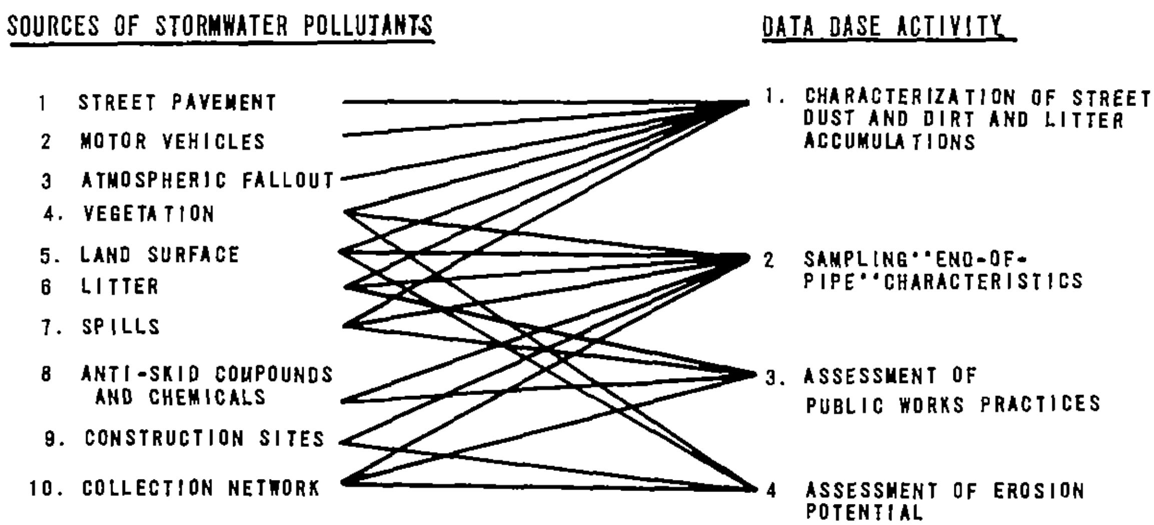

Figure 2. Relationships between sources of stormwater pollutants and data base activities.

- Stormwater discharge characteristics are becoming better defined, and, predictably, as the data base grows the spread between "average" values is significantly reduced. The reductions are apparent in Figure 3, which compares the present data base (from more than 2500 and 2200 samplings respectively, for separate stormwater discharges and combined sewer overflows) to those presented in the 1973 assessment [1]. Typical values are shown in Table 3.

- Data normalization has been performed by (1) system type, (2) mass (flow weighted) loadings, (3) land use, (4) precipitation and runoff characteristics, and (5) time (both within a specific event and as a function of intervals between events). A major deficiency in historical data is the absence of quantity-quality synchronization.

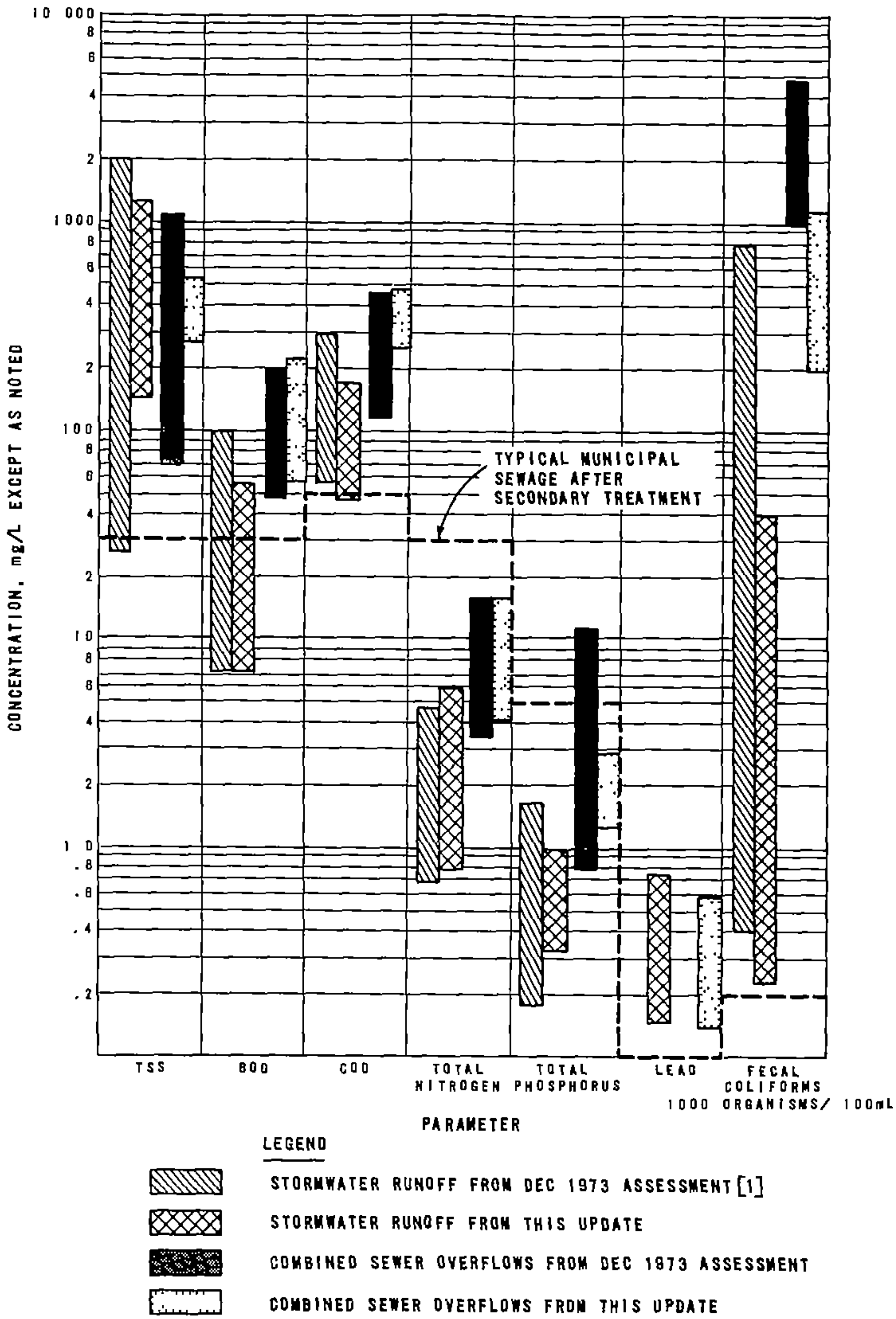

Figure 3. Representative stormwater discharge quality.

TABLE 3. COMPARISON OF TYPICAL VALUES FOR STORMWATER DISCHARGES[a]

	TSS	VSS	BOD	COD	Kjeldahl nitrogen	Total nitrogen	PO_4-P	OPO_4-P	Lead	Fecal coliforms
Background levels	5-100	...	0 5-3	20	...	0 05-0.5[b]	0 01-0 2[c]		<0.1	. ..
Stormwater runoff	415	90	20	115	1.4	3-10	0.6	0.4	0 35	14 500
Combined sewer overflow	370	140	115	375	3 8	9-10	1 9	1 0	0 37	670 000
Sanitary sewage [6]	200	150	375	500	40	40	10	7	.	. ....

a. All values mg/L except fecal coliforms which are organisms/100 mL

b. NO_3 as N

c Total phosphorus as P

Results of data normalization by system type, parameter, and time into event are shown in Figure 4.

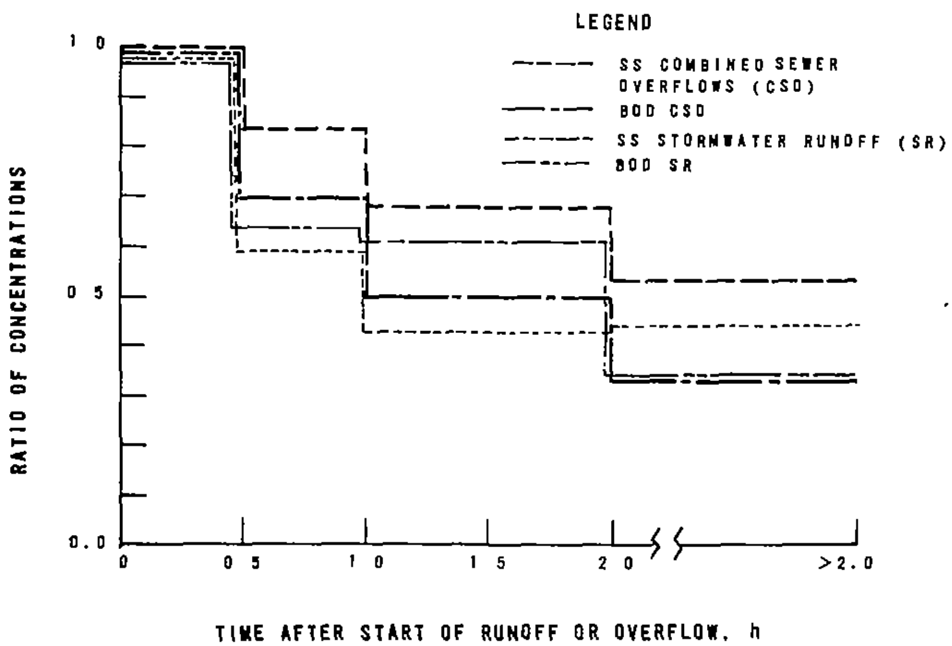

Figure 4. Time weighted normalization.

- Residual sludges from stormwater treatment processes are likely to be high in inorganics (volatile solids content about half that in raw primary sludge), treatable by conventional processes, but so great in volume as to provide major treatment and disposal problems. Further characterization and design experience are significant research needs.

- Receiving water impact evaluations to date must rely on model simulations due to the intermittency and variability of events and the masking effects of other discharges.

BEST MANAGEMENT PRACTICES

Nonstructural and low structurally intensive alternatives, termed best management practices (BMPs), offer considerable promise as the first line of action to control urban runoff pollution. By treating the problem at its source, or through appropriate legislation curtailing its opportunity to develop, multiple benefits can be derived. These include lower cost, earlier results, erosion/flood control benefits, and an improved and cleaner neighborhood environment.

- Problem prevention goals center about containment of all or part of the runoff and pollutants near the source. Planning elements include:

  1. Utilization of greenways and detention ponds

  2. Utilization of pervious areas for recharge

  3. Avoidance of steep slopes for development

  4. Maintenance of maximum land area in a natural undisturbed state

  5. Prohibiting development on flood plains

  6. Utilization of porous pavements where applicable

  7. Utilization of natural drainage features

- Construction controls such as minimizing the area and duration of exposure, protecting the soil with mulch and vegetative cover, increasing infiltration rates, and construction of temporary storage basins or protective dikes to limit storm runoff can significantly reduce receiving water impacts caused by erosion.

- Corrective maintenance and operation practices include:

  1. Control of litter, debris, and agricultural chemicals

  2. Regular street repair and sweeping

  3. Improved roadway deicing and materials storage practices

4. Proper use and maintenance of both catchbasins and drainage collection systems

5. Onsite retention or detention of stormwater runoff

- Program success is dependent on legislation or ordinances, to force or encourage conformance with the intended BMP, and a concerted effort to monitor compliance and educate not only those who will bear the responsibility of regulation, but the public as well.

- The greatest difficulty faced by BMP is that the action-impact relationships are almost totally unquantified. It is clear that onsite storage, for example, can be closely related to reduced downstream conduit requirements; but the net water quality benefits are far less defined. Similarly, cleaner streets and neighborhoods and enforced legislation will eradicate gross pollution sources, but to what limit should they be applied and who will bear the cost? The final answers of cost effectiveness have not been found short of trial implementation.

UNIT PROCESSES

The alternatives, or preferably supplements to BMP, involve combinations of storage and high-rate unit processes and/or conjunctive use with existing treatment facilities.

- Storage is considered a necessary control alternative because of the high volume and variability associated with storm and combined sewer overflows. Storage facilities are frequently used to attenuate peak flows, thereby reducing the size of facilities required for further treatment. Storage, however, with the resulting sedimentation that occurs due to increased detention times, can also be considered a treatment process, as shown in Figure 5.

- Inline storage, the use of the unused volume in interceptors and trunk sewers to store runoff, is a particularly attractive option for controlling urban runoff. Typically, this alternative includes installation of effective regulators, level sensors, tide gates, rain gage networks, sewage and receiving water quality monitors, overflow detectors, and flowmeters, and then applies computerized collection system control. System effectiveness may be highly sensitive to the degree and maintenance of the control system as shown in Figure 6.

- Physical treatment alternatives are primarily applied for solids removal from wastestreams, and are of particular importance to storm and combined sewer overflow treatment for removal of settleable and suspended solids and floatable material. Physical treatment systems have demonstrated capability to handle high and variable influent concentrations and flowrates and operate independently of other treatment facilities, with the exception of treatment and disposal of the sludge/solids residuals. The principal disadvantage relates to those periods of time when equipment sits idle during periods of dry weather. When implemented on a dual-use basis as either pretreatment or

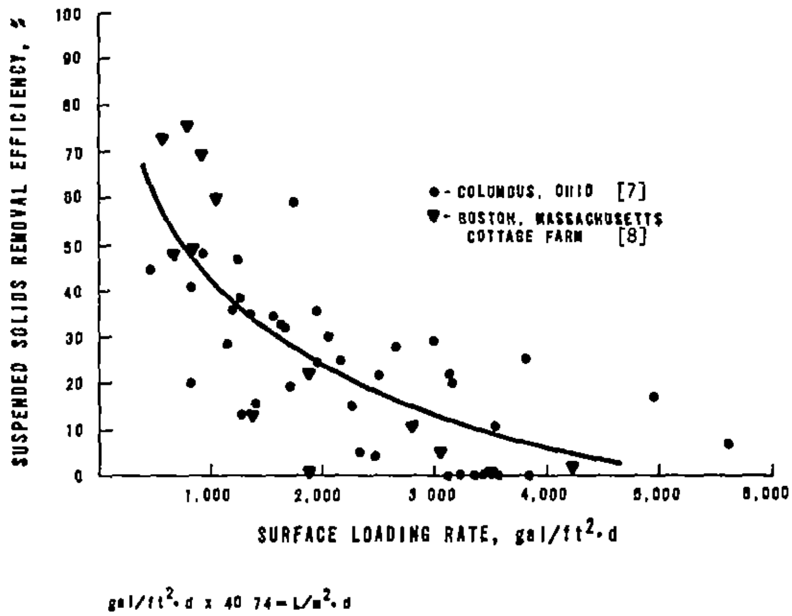

Figure 5. Typical suspended solids removal efficiencies for storage/sedimentation facilities without chemical addition.

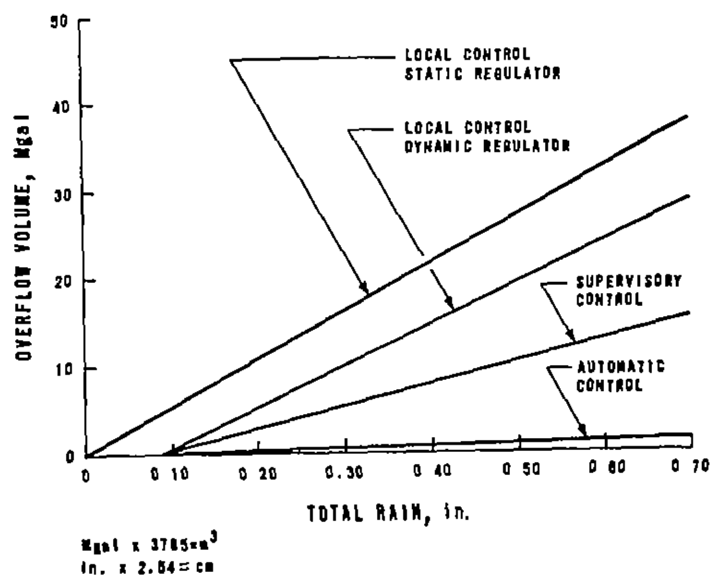

Figure 6. Inline storage effectiveness regression lines for each mode of control (Seattle).

effluent polishing of conventional treatment plant flows, reduced capital investments may be realized. Representative process efficiencies and costs are shown in Table 4.

TABLE 4. COMPARISON OF PHYSICAL TREATMENT SYSTEMS

Physical unit process	Percent reduction: Suspended solids	BOD_5	COD	Settleable solids	Total phosphorus	Total Kjeldahl nitrogen	Average capital cost, \$/Mgal·d[a]
Sedimentation							
Without chemicals	20-60	30	34	30-90	20	38	23 000
Chemically assisted	68	68	45	. .		.	23 000
Swirl concentrator/flow regulator	40-60	25-60	..	50-90	.	.	4 500
Screening							
Microstrainers	50-95	10-50	35	...	20	30	19 500
Drum screen	30-55	10-40	25	60	10	17	19 300
Rotary screens	20-35	1-30	15	70-95	12	10	19 900
Disc screens	10-45	5-20	15	.....		.	. .
Static screens	5-25	0-20	13	10-60	10	8	17 600
Dissolved air flotation[b]	45-85	30-80	55	93[c]	55	35	34 000
High rate filtration[d]	50-80	20-55	40	55-95	50	21	58 000
High gradient magnetic separation[e]	92-98	90-98	75	99	.		. ...

a. ENR Construction Cost Index 2000.

b Process efficiencies include both prescreening and dissolved air flotation with chemical addition.

c From pilot plant analysis [9]

d. Includes prescreening and chemical addition.

e From bench scale pilot plant operation, 1 to 4 L/min (0.26 to 1.06 gal/min)

- The effects of chemical addition to enhance the physical removal properties have been demonstrated for most unit processes and generally show increased pollutant removals and a tolerance for higher hydraulic loading rates. Chemical addition to dissolved air flotation and high rate filtration processes have shown the greatest performance improvement, generally ranging to 20% and higher. Paced control of chemical additions continues to be a major problem, however.

- Of the physical processes, screening has received the greatest attention during the study period of this update. In general, performance in early prototype scale has been below expectations and unit costs significantly higher. Comparative screen performances are shown in Figure 7.

- Swirl concentrator/regulators have shown a steady and attractive solids removal performance over a wide range of hydraulic loading rates. Units have been demonstrated up to 3.6 m (12 ft) in diameter for design flows up to 300 L/s (6.8 Mgal/d). The swirl flow principle has also been successfully demonstrated as a grit separation device and as a primary (treatment) separator (effectiveness presently limited to relatively small diameter, 5.5 m [18 ft] units) [10, 11]. Investigations are proceeding on its potential use as a portable erosion/construction site treatment device [12].

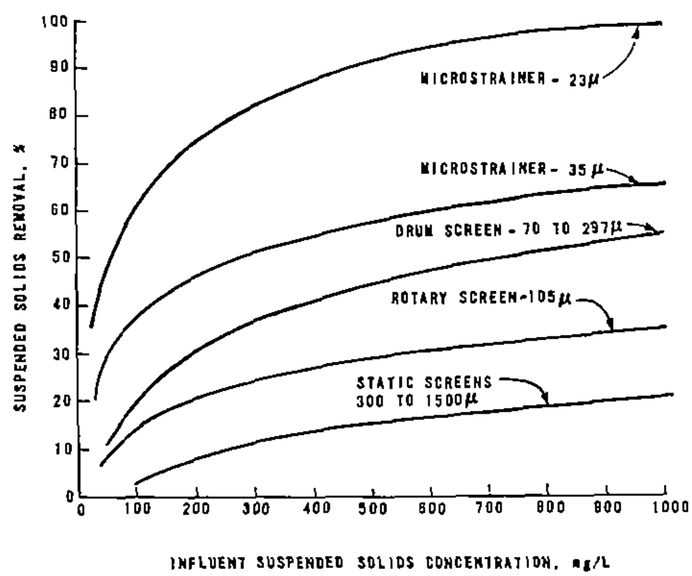

Figure 7. Comparative screen performance.

- Development and testing of new biological treatment processes and further demonstration of established stormwater biological systems at other locations have not been attempted beyond the originally reported demonstration facilities in reference [1].

- Land treatment of stormwater is limited by hydraulic application rates and the resulting land area requirements. Potentially promising processes include wetlands development, rapid infiltration, and overland flow. Conclusive design, operating, and performance data are unavailable. Marsh systems can handle the high solids loading associated with stormwater runoff and management techniques to increase pollutant removals are available from other field studies.

- Costs of disinfection systems used to treat combined sewer overflows and stormwater discharges can vary greatly depending on the complexity of the system. Stormwater disinfection must be flexible and capable of automatic operation to handle intermittent and varying flows and volumes.

High rate oxidizing agents, agent storage and handling, and high intensity mixing are major design considerations.

- In practice, operation and maintenance costs for stormwater facilities may show a marked economy of scale as shown in Figure 8. The illustration represents a cost to volume normalization of nine demonstration storage facilities.

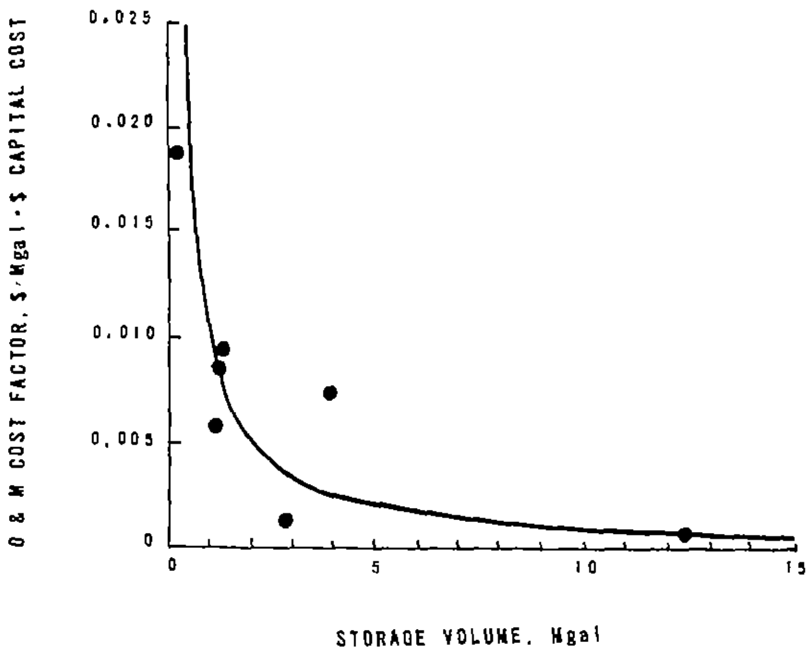

Figure 8. Operation and maintenance cost function for storage facilities.

SYSTEM APPLICATIONS

The size and complexity of urban runoff management programs are such that there is a need for an integrated approach to their solution. The solution is most often a combination of various best management practices and unit process applications.

- Regulatory constraints and public attitudes on pollution and environmental objectives are subject to change with time, thus mandating flexibility as a major program criterion.

- Demonstrated implementation progress to date is predominately in the areas of CSO control, excess flow treatment from heavily infiltrated sanitary systems, and BMP applications in new communities.

- Capital cost investments for structurally intensive alternatives commonly range from \$3000 to \$10 000/ha (\$8000 to \$24 000/acre) of sewered area. Degree of control varies from coarse screening and disinfection to complete secondary treatment with recreational reuse.

SECTION 3

RECOMMENDATIONS

The dollar investment in federally funded research and development (R&D) projects for stormwater management is dwarfed by the existing and potential construction costs generated off this data base. For example, Chicago's potential investment of $662 million in this, the first, year of its construction program is more than 10 times the total federal share in all storm and combined sewer R&D projects over the past twelve years since program inception. If the required technology base is to keep pace with or lead activities on such a scale, much greater emphasis must be given to the R&D effort with particular attention to the following.

IMPACTS AND BENEFITS

- Ties between receiving water quality and stormwater discharges must be clearly delineated in a wide variety of circumstances. This will require continuous monitoring of the selected discharge flows and the affected receiving water bodies to observe temporal and spatial impacts.

- Quantification of the impairment of beneficial uses and water quality objectives by such discharges should be a major criterion of these studies.

- As an alternative to direct discharge, beneficial reuse--the acceptance of urban runoff as a potential water resource--should be singled out as a prime R&D area. What are the potentials? What are the hazards? Why might runoff be preferred over other sources? How can reliability be built into designs to serve what specific uses? What is the cost outlook? For example, can highway drainage be ponded and reused for landscape irrigation?

- Renovated river systems, such as the San Antonio River in San Antonio, Texas, and the South Platte River in Denver, Colorado (Figure 9), should be fully researched and touted as clear evidence of documented benefits to be derived from improved stormwater management. These benefits include increased property values, alleviation of health and sanitation hazards, increased recreational facilities and linear parks, flood control, and enhanced community pride and quality-of-life [1].

- Finally, the potential beneficial reuses of the sludge by-products of stormwater treatment should be systematically evaluated. Is it suitable for direct landfill? If washed, will it prove to be a suitable foundation and grading material? Fine aggregate substitute? Cover material for refuse landfills?

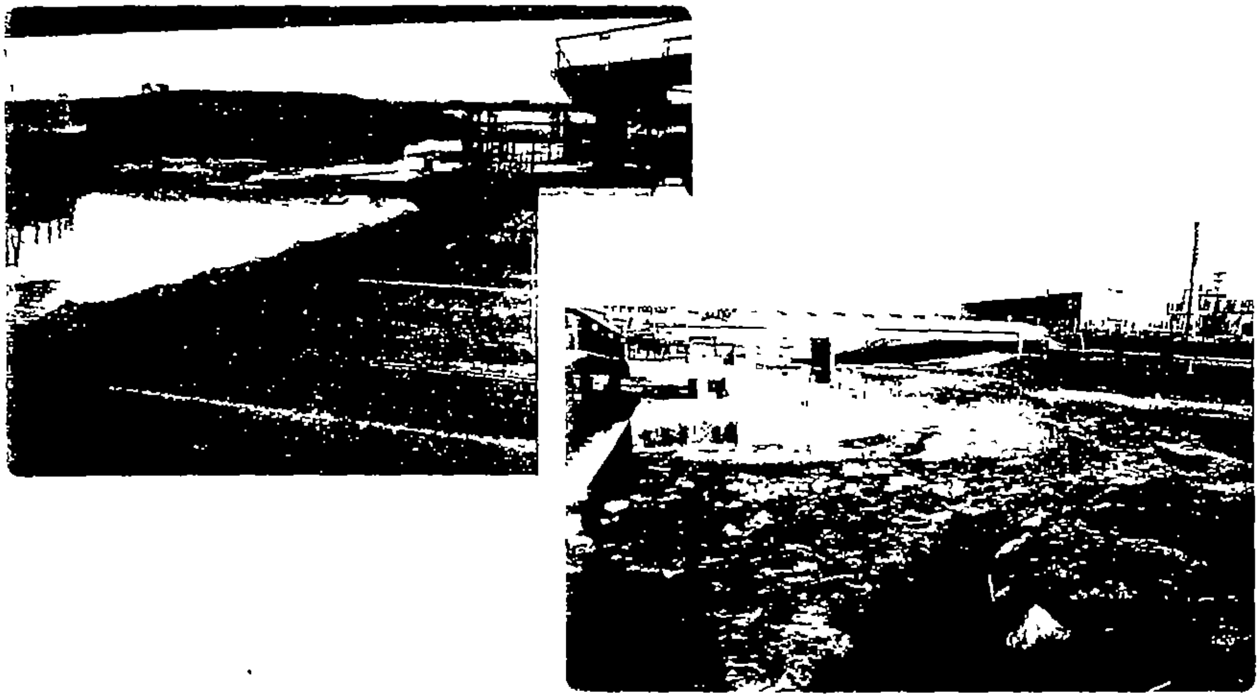

Figure 9. South Platte River Renovation Project, Denver, Colorado.

BEST MANAGEMENT PRACTICES

- Quantification of BMP action-impact relationships should be sought through multiple, broadscale, and regionally dispersed demonstration projects. Using runoff loadings, cost, and methodologies as primary criteria, comparisons of undeveloped versus developed and intensely applied BMP versus controlled no-action areas should be fully documented.

- Implementation, legislative, education, and enforcement experience gained from areawide studies on a national basis should be researched, consolidated, and published for local and subregional guidance and information.

UNIT PROCESSES

- The changes in stormwater characteristics as affected by storage should be analytically researched and published in a single subject document.

Specific interests concern odor generation, solids settlement and resuspension, and waste stabilization.

- The feasibility of pretreating and storing runoff in combined systems and subsequent reuse for system flushing should be investigated and demonstrated on a prototype scale.

- The dual-use application experience of new physical and, if applicable, biological stormwater treatment prototype systems should be researched in depth and published in a single subject document.

- The role of wetlands in the natural treatment of urban runoff and in the self-purification of streams should receive increased attention and information dissemination. Augmentation through applied land treatment technology should be investigated.

DATA MANAGEMENT AND DISSEMINATION OF INFORMATION

- Centralized storage and retrieval systems for stormwater quantity/quality and impact data, either regionally or nationally, are recommended as an adjunct to the essential free and rapid flow of priceless data between the researcher and the user.

- Information should be logged as quickly as possible and tagged with an identifier based on the degree of prescreening and verification of entries accomplished. All data not screened and verified within a specified time of posting, say 6 months, should be dropped from the system.

- All funded prototype demonstration projects should have a mandatory, preformatted, reporting requirement to the system on a monthly or bimonthly basis.

- When of significant program interest, funding for continuous monitoring and reporting beyond the normal project duration should be provided.

- Access to the data bank system should be open to anyone at nominal charge. Semiannual listings and updates of logged material should be published.

- Because of the continuing proliferation of publications in the field and the tendency towards rapid data obsolescence, universal assessments such as presented in this volume and its predecessor should give way to restricted subject area documents, thus permitting more in-depth analysis.

SECTION 4

APPROACH METHODOLOGY

The multivariable and complex nature of stormwater management assessments makes systematic approaches essential. Benefits to be derived from well structured and documented procedures include the identification of local data strengths and weaknesses, transferability of findings, and progressive adaptation to new technology and data sources. The information presented in this section provides the framework for the user to structure solution-oriented approaches and demonstrates their applicability through illustrative problem solving. Subsequent report sections provide data, management practice, unit process, and experience updates to be utilized in turning the approaches into practice.

INTRODUCTION

Two items have primary significance in framing approaches: (1) the basic concept and (2) the level of analysis required.

The Basic Concept

The basic approach may be viewed as consisting of four major steps.

Step 1. An effective approach methodology must be built on a quantified need. Thus, a logical first cut approach will intermix (1) known drainage area characteristics and hydrology, (2) reasonable ranges of pollutant-washoff and source potential, (3) background and direct discharge (point source) loadings, and (4) prevailing water quality conditions versus objectives. The purpose is to predetermine how much of what problem associated with what event frequency could be attributed to urban runoff dynamics.

Step 2. Selective field monitoring, guided by such analyses, should be concentrated in critical stream reaches and representative catchments. This second level investigation is necessary to substantiate the local applicability of assumed "best fit" data and to refine estimates.

Step 3. With the problem quantified and substantially isolated, a cost-effectiveness assessment of abatement alternatives has an improved likelihood of success. In this assessment, unit processes and improved management practices, singly or in combinations, are applied to the problem, costs established, and performance (benefits) quantified.

Step 4. Finally, repeat simulations of the receiving waters, loaded under post plan conditions, may be performed to yield a measure of the improvements potentially attainable.

Level of Analysis

The program for urban stormwater management for water quality benefits is a new and developing art. However, pressures for rapid, balanced control and restoration of receiving water quality have forced the program to center stage alongside the relatively mature programs of municipal and industrial wastewater treatment with several decades of experience behind them.

Fortunately, this condition has spawned several tools and methodologies for identifying and attacking stormwater problems, ranging from simple desktop procedures and nomographs to extremely complex computer simulations with 1 to 3 minute real time iteration cycles and with provisions for backwater, surcharging, looping, etc. Unfortunately, however, the core data on which quantitative assessments are built today are strikingly similar, marking the more complex approaches with a stigma of potential overkill.

Just as federal/state basin programs progress from waste load allocation (Section 303(e) [1]) through problem identification and assessment (Section 208) to facilities planning, design, construction, and operation (Section 201), so should the user be guided in his selection of tools and level of analysis. Desktop procedures may be entirely adequate for waste load allocations on the majority of streams that have minimal historical quality records. Simplified models add the benefits of total system perspective and time variability for advanced planning for problem identification and assessment. Finally, detailed models provide the consistency and precision for final design evaluations and post construction assessments. Each level of analysis and the applicable tools will be addressed in the body of this section.

CHARACTERIZATION OF THE NATIONAL PROBLEM

Under contract to the EPA, a joint effort of the American Public Works Association (APWA) and the University of Florida has recently produced a Nationwide Assessment of Combined Sewer Overflows, Urban Stormwater Discharges, and Nonsewered Urban Runoff [2]. The methodology used, the assumptions made, and problems encountered are of interest and potentially applicable on both regional and subregional analyses. Selected conclusions from that study follow:

- Dry-weather flows represent 30 to 50% of the total runoff from urban areas [the balance being wet-weather flows].

- Wet-weather organic loads from combined sewered areas are approximately four times higher than those from separate sewered areas.

- Loading rates [pollutant releases to receiving waters] for untreated dry-weather flow are higher than for wet-weather flow. However, if 90% secondary treatment is assumed for dry-weather BOD generation, wet-weather loads are seen to be a significant portion of the total loadings from urban areas.

- A generalized method for evaluating the optimal mix of storage and treatment for wet-weather pollution load reduction indicated that a primary type facility is preferable up to BOD removals of about 10%. A secondary facility is preferable for higher levels of control.

- The "first flush" assumption, i.e., the assumed pollutant washoff rate, has a significant impact on the assessment. Control costs are about one-third less if a first flush is assumed.

- Incremental costs for wet-weather control increase significantly with higher control objectives. This is due to the disproportionately larger control units needed to capture the less frequent, larger storms.

- Significant savings might be realized [30 to 70%] by integrating wet-weather quantity control [storage] and dry-weather quality control [joint use of "excess" treatment capacity].

- Approximately 39% of the combined sewer problem and 10% of the other wet-weather flows should be controlled before initiating tertiary treatment control on a national average basis using BOD removal as the effectiveness measure.

- Runoff [wet weather] pollution can govern the quality of receiving waters due to the shock effect and long-term buildup of solids [benthic demands, turbidity, and smothering of attached aquatic growths and organisms].

An important additional finding of the study was the identification of the gross inadequacies of the present data base and the high sensitivity of the conclusions to the assumptions [ground rules] required for simulation. The major techniques applied and assumptions made are discussed in the following subsections and in Section 5.

PLANNING GUIDES

Guides to planning the management of urban stormwater quality may be divided into the following five principal components for the convenience of their users:

- Determination of stormwater quantity and quality at the outfall or interceptor

- Evaluation and selection of control alternatives

- Analysis of receiving water impacts